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# Energy efficiency and sustainable growth in the industrial sector, evidence of European Union countries, Nonlinear ARDL approach

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# Resumo

Eficiência energética e crescimento sustentável são um alvo a atingir para muitos países. Considerando este foco, este trabalho centra-se na análise da relação entre a eficiência energética do sector industrial e o crescimento económico para o período de temporal de 1997 a 2013 em 11 países da União Europeia. Para esta análise foi utilizado o modelo NARDL, de forma a analisar efeitos de curto e longo-prazo, bem como movimento ascendentes e descendentes das varáveis consideradas neste estudo. Após a análise efetuada algumas das principais conclusões deste estudo revelam que o investimento efetuado pelo sector empresarial está a ser feito no sentido de atingir a eficiência energética e simultaneamente a redução de emissão de gases efeito de estufa *(GHG)*. Outro resultado importante é o impacto do crescimento económico na eficiência energética, sendo que se verifica que o crescimento económico impulsiona o aumento da eficiência energética. Este resultado também se verifica com o índice de preços de energia do sector industrial, sendo que a existência de um preço incentiva o aumento da eficiência energética. Como robustez foi efetuada a curva de Kuznets ambiental *(EKC)*, com o $GDP_{PC}$ e como alternativa o *IPI*, de forma a perceber como atingir a eficiência energética bem como o crescimento sustentável. Estes resultados revelam que os decisores políticos devem melhorar e criar novas politicas de incentivo ao crescimento sustentável e à eficiência energética. Politicas essas que se podem centrar no conceito de gestão da procura *(DSM)*, como o *real-time pricing*, ou politicas de incentivo ao investimento e desenvolvimento tecnológico.

# Palavras-Chave

Eficiência Energética; Crescimento Sustentável; Nonlinear ARDL, Curva de Kuznets ambiental; União Europeia; Sector Industrial

# Resumo alargado

A necessidade de aprofundar a eficiência energética e a sua compatibilização com o crescimento sustentável são dois dos principais desafios que se colocam aos países. É cada vez mais importante perceber quais as melhores formas de atingir a eficiência energética e o crescimento sustentável, bem como os seus principais benefícios de forma a promover melhorias ambientais sem diminuir o crescimento económico.

Vários estudos têm vindo a ser realizados no âmbito da relação entre o crescimento económico e a degradação ambiental. Estes revelam que o crescimento económico está diretamente relacionado com a degradação ambiental. Estes estudos defendem que para promover o crescimento económico de forma rápida é necessário aumentar o consumo de energia. Estes aumentos de consumo de energia traduzem-se em aumentos de emissões de gases com efeito de estufa, o que leva ao aumento da degradação ambiental. Esta degradação revela-se um grande entrave ao crescimento de forma sustentável o que nos dias de hoje é uma grande preocupação para as sociedades. De forma a colmatar este efeito, vários estudos têm vindo a ser feitos no âmbito da eficiência energética com o objetivo de reduzir o consumo de energia, ou seja, uma utilização eficiente, e consequentemente a redução de emissões de gases efeito de estufa, sem provocar um abrandamento no crescimento económico.

O conceito de eficiência energética foi introduzido na literatura por Farrell (1957). Este conceito defende o uso de menos energia para obter o mesmo ou maior número de bens e serviço. O estudo da eficiência energética centra-se em uma abordagem *DEA* (Data Envelopement Analyses), embora autores como Heidari, Omid, e Akram, (2011), Houshyar, Zareifard, Grundmann, e Smith, (2015) e Li e Tao, (2017) defendem que a mesma analise poderá ser efetuada através de uma abordagem econométrica. Por sua vez, o conceito de crescimento sustentável tem vindo a ser abordado na literatura através da aplicação da curva de Kuznets (*EKC*) (Kuznets, 1955). Este conceito defende que a obtenção de uma curva em forma de "U" invertido evidencia que as emissões de *GHG* crescem juntamente com o crescimento económico até ao ponto de viragem, iniciando nesse ponto uma diminuição dessas emissões.

O objetivo deste estudo é contribuir para a literatura, com uma análise da relação entre eficiência energética e crescimento económico sustentável, bem como ajudar a definir alguns dos melhores meios para atingir a eficiência energética e o crescimento sustentável. Para isso foram utilizados dados anuais desde 1997 a 2013, para um painel de 11 países membros da

União Europeia. Este estudo centra-se na análise da relação da eficiência energética do sector industrial com o crescimento económico e as emissões de gases efeito de estufa (*GHG*). As variáveis utilizadas neste estudo foram, o Índice de Eficiência Energética (*EEI*) introduzido na literatura por Li e Tao, (2017) e Patterson, (1996), calculado a partir da divisão do *IPI* (Índice de produção industrial) pela Energia (Energia consumida pelo sector industrial), representado o crescimento económico e utilizado o Índice de produção industrial (*IPI*) e como componente ambiental foram utilizados os gases de efeitos de estufa (*GHG*).

De forma a analisar qual a melhor forma de atingir o crescimento económico sustentável e eficiência energética foram incorporadas as seguintes variáveis: o Investimento efetuado pelo sector empresarial (*I*), taxa de emprego do sector industrial (EMPR),índice de preços de energia do sector industrial (*IEPI*), eletricidade produzida pela fonte hidroelétrica (*HYDRO*), eletricidade produzida pela utilização de petróleo (*OIL*), eletricidade produzida pelas fontes renováveis (*RES*) e eletricidade produzida pelo carvão (*COAL*). As variáveis foram convertidas em logaritmos naturais e foram calculadas as respetivas diferenças.

Em primeiro lugar foi analisada a matriz das correlações onde foi possível verificar que não existem problemas de colinearidade entre as variáveis. Em seguida foram efetuados dois tipos de testes de raízes unitárias (primeira e segunda geração), de forma a perceber qual a ordem de integração das séries. Após a analise dos testes, foi possível verificar que não existem variáveis com ordem de integração superior a um, o que revela que a utilização dos modelos ARDL e NARDL é apropriada. De forma a perceber qual o modelo a aplicar se efeitos fixos ou efeitos aleatórios foi efetuado o teste de Hausman, o qual revelou que o melhor modelo a aplicar será o de efeitos fixos. Após se verificar a utilização de efeitos fixos foram realizados outros testes diagnostico como: i) cross-section dependence, heterocedasticidade e autocorrelação de primeira ordem. A analise destes testes revelaram a presença de cross-section dependence, heterocedasticidade e autocorrelação de primeira ordem, estes resultados revelam que o estimador mais apropriado para o tipo de dados utilizados é o estimador Driscoll-Kraay.

De forma a responder à questão central deste estudo foram utilizadas duas metodologias, a saber ARDL e NARDL. Estas metodologias estudam os efeitos de curto e longo prazo em simultâneo das diferentes variáveis. Enquanto que o modelo ARDL analisa apenas as variáveis em dois momentos, curto e longo prazo, o modelo NARDL analisa as variáveis em quatro momentos diferentes, curto e longo prazo, e ascendente e descendente. Estas duas metodologias permitem ainda a utilização de variáveis com ordem de integração *I(0)* e *I(1),* bem como a inclusão de variáveis dummy. Esta analise permite um estudo mais pormenorizado e com possibilidade de observar diferentes efeitos provocados pela mesma variável, o que leva a que a metodologia principal deste estudo seja o modelo NARDL.

Foram efetuados dois modelos ARDL e dois modelos NARDL, onde as variáveis dependentes são o *EEI* e o *IPI*, de forma a perceber os efeitos entre a Eficiência Energética e o Crescimento Económico. Foi efetuada também uma analise ambiental através da curva de Kuznets, onde se verifica a presença de uma curva em forma de “U” invertido, onde é também possível verificar qual o efeito da eficiência energética nas emissões de *GHG*.

Os resultados obtidos revelam uma relação bidirecional entre o crescimento económico, a eficiência energética do sector industrial e as emissões de *GHG*. Esta relação revela que a eficiência energética provoca um aumento no crescimento económico. O mesmo resultado também se verifica no sentido do crescimento económico para a eficiência energética, visto que o crescimento económico mesmo quando é descendente tem impacto positivo na eficiência energética. Em relação à ligação entre os *GHG's* e a eficiência energética verifica-se uma relação negativa, tanto nos momentos ascendentes como descendentes de ambas as variáveis. Em relação à ligação entre o crescimento económico e as emissões de *GHG* verifica-se um sinal positivo entre o crescimento económico e os *GHG's*. Comprova-se ainda a existência da curva de Kuznets, dado que tanto o *IPI* como $GDP_{PC}$ ao quadrado tem um sinal negativo, como evidenciado na literatura.

Os resultados obtidos comprovam que o crescimento económico impulsiona a economia no sentido de eficiência energética. Contudo, no caso de um abrandamento do crescimento verifica-se uma desaceleração da eficiência energética, continuando a influenciar positivamente, porém de forma mais lenta. O investimento efetuado pelo sector empresarial revela-se também um componente importante. Este influencia simultaneamente o crescimento económico e a eficiência energética no momento ascendente de forma positiva e no momento descente o mesmo tem influencias nefastas para económica, causando uma diminuição do crescimento económico e da eficiência energética, obrigando assim a economia a retomar o crescimento de uma posição inferior, sendo necessário redobrar os esforços para atingir crescimento económico.

Os *policymakers* devem ter em consideração os principais componentes que levam a um crescimento sustentável e eficiente. Utilizando com conceito de *Demand Side management* (*DSM*), o preço da energia revela-se útil de forma a maximizar a eficiência energética e o crescimento económico. O mesmo deverá ser alto o suficiente para incentivar as empresas a investir em tecnologia mais eficiente, no entanto o mesmo não poderá ser demasiado alto de forma a constringir o crescimento económico. Os *policymakers* devem aplicar políticas de incentivo à migração para tecnologias mais eficientes e regular o preço da energia de forma a evitar ineficiências e abrandamento do crescimento económico.

## Abstract

Energy efficiency and sustainable development, are the focus of many countries in the current times. This work analyses the energy efficiency in the industrial sector for 11 European Union countries for the time span of 1997 till 2013. The applied methodology focuses on the Nonlinear ARDL model, which allows to analyses the short and long run relationships in the ascending and descending movement of the variables. The main results indicate that the investment made in the economy are incremating energy efficiency and reducing the greenhouse gases (*GHG*). Economic growth is pushing the economy towards energy efficiency the same output is found in the Industry energy prices index. As robustness, the Environmental Kuznets curve using the $GDP_{PC}$ and as an alternative, the IPI are estimated. To ensure a rapid growth of energy efficiency and sustainable growth policymakers, must change and build new policies that lead to a greater investment to achieve the sustainable and efficient growth.

## Keywords

Energy Efficiency; Sustainable Growth; Nonlinear ARDL, Environmental Kuznets Curve; European Union; Industrial Sector

# Index

# Tables List

# Acronyms list

AECM - Asymmetric Error Correction Mechanism

ARDL - Autoregressive-Distributed Lag model

COAL - Electricity Produced by Coal

DDF - Directional Distance Function

DEA - Data Envelopment Analyses

DSM - Demand-side Management

ECM - Error Correction Mechanism

EEI - Energy Efficiency Index

EKC - Environmental Kuznets Curve

EMPR - Employment Rate in the industry sector

Energy - Energy Consumption of the Industrial Sector

GDPPC - Gross Domestic Product per capita

GHG - Greenhouse Gases

HYDRO - Electricity Produced by Hydroelectric Source

I - Investment of the Business Sector

IEPI - Industry Energy Prices Index

IPI - Industrial Production Index

MPI - Malmquist Productivity Index

M-Radial - Modified Radial

NARDL - Nonlinear Autoregressive Distributed Lag model

OECD - Organization for Economic Cooperation and Development

OIL - Electricity Produced by Oil Sources

Output - Industry Added Valued

RAM - Range Adjusted Model

RES - Electricity Produced by Renewable Source

RMM - Russel Measure Model

SBMT - Tone’s Slack-Based Model

SFA - Stochastic Frontier Production Function Model

# 1. Introduction

In the current times, countries are looking for ways to grow without harming the environment. To achieve the sustainable growth, countries start to develop different ways to produce energy/electricity, such as the wind and solar. The use of such alternative sources, allows the industry sector to produce with low Greenhouse gases (*GHG*).

The industry represents the main sector for many European countries, which is the area that contributes most to economic growth. Different policies have been implemented in this sector to promote an efficient use of energy. Allowing to obtaining the same output with the use of less energy, and with less *GHG* emissions, generating economic growth with the use of fewer resources and expenses.

The focus of the work is analysing the energy efficiency in the industrial sector; this area has the higher demand and consumption of energy. The main questions are: Is the European industry running towards energy efficiency? There is a relationship between the environment, economic growth and energy efficiency? Is economic growth pushing the economy towards energy efficiency? Which effects the acceleration and deceleration of investment reflect in economic growth and energy efficiency? In one hand, such analyses are crucial to understanding if the current energy efficiency policy and investment are implemented in proper ways. In another hand, such measures are maybe not promoting a more efficient industrial sector. Such analyses allows policymakers to evaluate the effectiveness of implemented measures.

The environmental component emerges as a parallel issue, since the main policies and actions influence both concepts at the same time, merging both is suitable and allows to obtain more robust and conclusive analyses. A general analysis is incorporating the sector as all and striping any restriction is implemented. The current literature is underdeveloped in such way; the main studies analyse the sector including only the major companies, our throw empirical analyses that do not allow a distinction between short and long run analyses.

Implementing a different methodology based on the current literature permit the confrontation of methods and establishes a point of comparison with the current literature. The used methods (ARDL and NARDL) allow the distinction of short-run and long-run and asymmetric effects. Such analyses have not been implemented in the current literature. Other main reason of use such methodology is the time spam, it covers almost two economic cycles. The use of this long temporal space allows to obtain robust results and allows to evidence the presence of cointegration.

## 2. Literature review

The author, Farrell, (1957) defines energy efficiency as the use of less energy to obtain the same volume our superior of goods and services. Patterson, (1996) defined two methods of analysing energy efficiency, (i) total factor and the (ii) single factor index. The total factor index is calculated using variables such as labour, technology, capital and other variables considered significant by the authors. The single factor index is calculated using a simple division of output (growth) by energy input.

The theoretical findings obtained by Farrell, (1957) were applied in statistical analyses by Aigner, Lovell, & Schmidt, (1977). Using a Stochastic Frontier Production Function Model (SFA), the authors obtained robust results by including an adequate characterization of disturbance term in the models. The authors study 100 power generation plants using as variables the fuel and labour while minimising the costs of energy production. To prove the obtained results, the authors compared the achieved results with the traditional covariance approach.

Other authors such as Li & Tao, (2017), Lin & Zheng, (2016), Seiford & Thrall, (1990), Song, Li, Zhang, He, & Tao, (2015) and Wei, Löschel, u, (2015) distinguish total factor energy efficiency in two major approaches, the non-parametric and parametric. The non-parametric approach uses the SFA model; the parametric applies the Data Envelopment Analyses (DEA). The non-parametric emerges in the literature as the most reliable. This method does not need any prior norms, avoiding bias caused by inappropriate assumptions.

The first methodology for studying energy efficiency using a parametric approach was proposed by Charnes, Cooper, & Rhodes, (1978) which introduce the linear programming into efficiency measurement (DEA). Appling such methodology Meng, Su, Thomson, Zhou, and Zhou, (2016) studied 30 Chinese provinces for the period of 1995 till 2012, proving a slight increment of efficiency at the end of the period of analyses. (W. Zhang, Pan, Yan, & Pan, 2017) applied the same methodology using a different time spam (2000-2014) encountered the same results as Meng et al., (2016).

The DEA approach allows the incorporation of different models. The models used are Radial, Modified Radial (M-Radial), Russel Measure Model (RMM), Tone's Slack based model (SBMT), Range adjusted model (RAM); and Directional distance function (DDF). The reference models were applied by the follow authors respectively, Shen, Zhou, & Zou, (2015), Pan, Liu, & Peng, (2015), Wu, Lv, Sun, & Ji, (2015), Ang, Xu, & Su, (2015), Wang, Zhao, Zhou, & Zhou, (2013) and N. Zhang & Wei, (2015).

Diverging from the DEA analyses Heidari, Omidand Akram, (2011), Houshyar, Zareifard, Grundmann, and Smith(2015), use an econometric approach. The achieved results were conclusive and consistent to the findings obtained from the DEA methodology. Li and Tao, (2017) reference that an econometric approach reveals to be suitable for an energy efficiency study.

Energy efficiency can also be related to sustainability and environmental degradation. Such analyse applied, by Kang and Lee, (2016) which studied 154 Korean companies and concluded that such enterprises had a positive relationship between efficiency and productivity. Using a different and larger sample, Kim and Kim, (2012), used two sets of countries dived by OECD members and non-members, a total of 43 countries. The authors dived in three industrials sectors (manufacturing, services and agriculture). With the time span starting in 1990 till 2016 with biannual frequency. The investigators indicate that the research is illustrative and the obtained results are biased, due to the fact of not including variables with no stochastic trend.

The author Chen and Golley, (2014), analysed 38 industrial sectors of China from 1980 till 2010. Using $CO_2$ emissions as an undesirable output by the industrial sector, revealing that the industrial sector of China is not interested in energy efficiency and sustainable growth.

Focusing on the European Union, Makridou, Andriosopoulos, Doumpos and Zopounidis, (2016) suited 23 European countries of five energy-intensive industries with the time span of 2000 till 2009. The authors implemented a DEA analyses using the Malmquist Productivity Index (MPI). The obtained results indicate that the energy-intensive industries are becoming more energy efficient with the use of technological progress.

Along with sustainable growth and energy efficiency, a new concept emerges in the current literature, the Demand-side Management (DSM) (Gyamfi, Amankwah Diawuo, Nyarko Kumi, Sika, and Modjinou, 2017). The DSM is the control of energy consumption applying different mechanism such as real-time pricing of energy (Alasseri, Tripathi, Joji Rao and Sreekanth, 2017; Bergaentzlé, Clastres and Khalfallah, 2014; Khan, Mahmood, Safdar, Khan and Khan, 2016; Meyabadi and Deihimi, 2017; Yang et al., 2017). Many authors have incorporated the energy pricing in energy efficiency studies (Du, Matisoff, Wang and Liu, 2015), allowing to evaluate the effect of pricing energy to reduce inefficiency. Indeed, such incorporation is suitable allowing to assess the effect of the DSM concept.

The literature concerning energy efficiency is mainly focused on the DEA and SFA methodology. The authors have not reached a consensus on which variables are suitable for such analyses. Such limitation can result in dubious results when applying the DEA and SFA technique. Other limitation found in the literature, is the methodology used since all approaches are focused on DEA models, such method cannot display a long-run relationship. Incorporation other methods of analyses can reveal more robust results and different perspective of analyses, such a short and long run analyses. Both methodologies are not possible to extrapolation the obtained results. The obtained results can only be applied to the sampling group. To overcome such limitations an econometric approach can produce robust results and can generalise the obtained results to all industries in the country of study.

To analyse a similar concept of sustainability is commonly used the environmental Kuznets curve, proposed by Kuznets (1955). This concept indicates that in the growing process the countries raise the industry level and similar raise the GHG emissions. The GHG emissions will reach the maximum (turning point), and then initiate the descending, formation an inverted U-shape curve (Zoundi, 2017).

The present study aims to overcome some limitations found in the literature. To do so, different variables referred in various studies were incorporated allowing an appraising of the results simultaneously. Other contribute is the applied methodology; two different methods were used. The ARDL and NARDL, allowing to distinguish the short and long run simultaneously and to verify the asymmetric results of the variables of the study. This perspective enriches the current literature and opens opportunities for futures studies.

# 3. Data and methodology

## 3.1 Data

This study uses annual data from European countries with the time span starting in 1997 till 2013 were included 11 countries. The countries analyzed were: Germany, Austria, Belgium, Finland, France, Italy, Netherlands, Poland, Portugal, Czech Republic and the United Kingdom.

The used variables are focused in the current literature, the Energy efficiency index (*EEI*) deserves a special comment, it was introduced in the literature by Patterson, (1996) and Li & Tao, (2017). The *EEI* is computed using the output of a respective sector divided by the energy consumption of the sector. The respective calculus equation is presented in equation (1). The remaining variables such as the Investment of the business sector (*I*), Greenhouse Gas (*GHG*), Industrial production index (*IPI*), Employment Rate in the industry sector ($EMP_R$), Industry energy prices index (*IEPI*), electricity produced by renewable source (*RES*), electricity generated by hydroelectric source (HYDRO), electricity generated by oil sources (*OIL*) and electricity generated by coal (*COAL*) are incorporated in different investigations (Li & Tao, 2017; Patterson, 1996).

$$EEI = \frac{Output_t}{Energy_t} \tag{1}$$

The equation (1), represents the used formula to compute the *EEI* Index. The $Energy_t$ operator indicates de energy consumption, and the $Output_t$ operator represents the output of the sector. In this study, it was used the Energy consumption of the industrial sector ($Energy_t$) and the Industrial Production Index ($Output_t$).

- Energy efficiency index (*EEI*) – This variable is used to measure the level of energy efficiency of the industrial sector, to be able to realise how many units of energy are needed to produce an output unit. The *EEI* is also divided ascendant and descendant to perceive its various effects on economic growth and to see how to achieve sustainable growth through energy efficiency.

- Investment of the business sector (*I*) – This variable represents the investment made by the corporate sector, absorbing the effect of the investment and technology development in the industry sector.

- Industry energy prices index (*IEPI*) – This variable represents the energy price index for the industrial sector, with the objective of measuring the effect of the price changes on the energy efficiency of the industrial sector. Incorporation the demand-side management concept.

- Industrial production index (*IPI*) – This variable represents the industrial production index, is used as a form of representation of economic growth, and industrial output.

- Employment rate in the industry sector ($EMP_R$) – This variable represents the employment rate of the industry sector and is used to observe the impact of employment both on energy efficiency and economic growth. Emerging as a control variable.

- Greenhouse gases (*GHG*) -This variable represents greenhouse gases emissions and represents environmental degradation.

- Electricity produced by the renewable source (*RES*) –This variable represents electricity generated from renewable sources and aims to analyse the impact of the energy generated by this source on energy efficiency and to see if this will be a possible source of production to achieve sustainable growth.

- Electricity generated by oil source (*OIL*) –This variable represents electricity generated by the oil, to understand how this source influences the energy efficiency of the industrial sector, as well as economic growth.

- Electricity generated by coal (*COAL*) –This variable represents the electricity generated by coal and is present in the study to verify the effect of this source of energy efficiency and economic growth.

- Electricity generated by the hydroelectric source (*HYDRO*) – This variable represents electricity generated by the hydroelectric source, this variable is inserted in the study to perceive the possible sources to promote energy efficiency and sustainable growth.

In Table 1 the summary of statistics can be appraised.

Table 1 – Descriptive statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max | Source |
|---|---|---|---|---|---|---|
| *LEEI* | 187 | -4.91474 | 0.760478 | -6.19996 | -2.97975 | Computed |
| *LIPI* | 187 | 4.550767 | 0.180679 | 3.883364 | 4.78661 | OECD |
| *LGHG* | 187 | 5.509311 | 0.906769 | 4.163814 | 7.019461 | European Commisson |
| *LI* | 187 | 25.84634 | 1.039105 | 23.93099 | 27.79541 | Eurostat |
| *LIEPI* | 187 | 4.474954 | 0.160561 | 4.00091 | 4.756207 | IEA |
| $LEMP_R$ | 187 | 3.309077 | 0.212079 | 2.727853 | 3.725693 | World Bank |
| *LRES* | 187 | 1.273679 | 1.183235 | -2.10922 | 3.438792 | European Commisson |
| *LHYDRO* | 187 | 1.339281 | 1.845156 | -2.98664 | 4.246685 | European Commisson |
| *LOIL* | 187 | 0.587282 | 1.224889 | -2.90864 | 3.827856 | European Commisson |
| *LCOAL* | 187 | 3.143749 | 0.855659 | 1.134931 | 4.571385 | European Commisson |
| $LGDP_{PC}$ | 187 | 10.47118 | 0.744471 | 9.591069 | 12.87676 | World Bank |

Notes: All variables converted to natural logarithms, the "PC" indicates per capita values.

## 3.2 Methodology

In this section, the used approach of data processing is explained. Firstly, two unit roots type tests were performed, first generation and second generation. The first generation unit root tests were developed by Breitung, (2000), I. Choi, (2001), Im, Pesaran, & Shin, (2003), Levin, Lin, & Chu, (2002) and Maddala & Wu, (1999). Second generation unit root tests proposed by Pesaran, (2007) which permits the presence of cross-section dependence.

It was analysed the presence of fixed effects and random effects using the Hausman test proposed by Hausman, (1978). Other diagnostic tests were applied such as time-fixed effects (Beale, 1960) (i), Cross-section Dependence (Breusch & Pagan, 1980; Pesaran, 2004) (ii), heteroskedasticity (Greene, 2000) (iii) and First order serial correlation (Wooldridge, 2002).

The diagnostics tests indicate that the Driscoll-Kraay estimator proposed by Driscoll & Kraay, (1998) is the one that best fits the used data. The Driscoll-Kraay estimator uses robust standard errors within a fixed effects estimation. Allowing to obtained robust results in the presence of the cross-section dependence, first order serial correlation and heteroscedasticity. This estimator can be implemented using different approaches such as the ARDL and NARDL models.

## 3.3 Autoregressive-Distributed Lag Model

The Autoregressive-Distributed Lag model (ARDL) proposed by Pesaran, Shin, & Smith, (2001), allows to analyse the short and long run effects and asymmetric evolution simultaneously, permits the use of variables with a different order of integration except for variables stationary only in second differences. The ARDL model allows for the use of dummies variables to correct possible outliers and generates a robust result with small samples. The obtained models can be specified as follows:

$$
\begin{aligned}
\Delta LEEI_{it} = {} & \alpha_{1t} + \sum_{n=0}^{k} \beta_{1\,2it}\Delta LGHG_{it-n} + \sum_{n=0}^{k} \beta_{1\,3it}\Delta LIPI_{it-n} + \sum_{n=0}^{k} \beta_{1\,4it}\Delta LRES_{it-n} \\
& + \sum_{n=0}^{k} \beta_{1\,5it}\Delta LCOAL_{it-n} + \delta_{2\,6it}LEEI_{it-1} + \delta_{2\,7it}LIEPI_{it-1} \\
& + \delta_{2\,8it}LIPI_{it-1} + \delta_{2\,9it}LGHG_{it-1} + \delta_{2\,10it}LOIL_{it-1} + \alpha_{2t}ID2004 \\
& + \varepsilon_{1it}
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
\Delta LIPI_{it} = {} & \alpha_{1t} + \sum_{n=0}^{k} \beta_{1\,2it}\Delta LGHG_{it-n} + \sum_{n=0}^{k} \beta_{1\,3it}\Delta LI_{it-n} + \sum_{n=0}^{k} \beta_{1\,4it}\Delta LEMP_{R\,it-n} \\
& + \sum_{n=0}^{k} \beta_{1\,5it}\Delta LCOAL_{it-n} + \sum_{n=0}^{k} \beta_{1\,6it}\Delta LIEPI_{it-n} + \sum_{n=0}^{k} \beta_{1\,7it}\Delta LEEI_{it-\mathrm{n}} \\
& + \sum_{n=0}^{k} \beta_{1\,8it}\Delta LHYDRO_{it-n} + \sum_{n=0}^{k} \beta_{1\,9it}\Delta LOIL_{it-n} + \delta_{1\,10it}LIPI_{it-1} \\
& + \delta_{1\,11it}LIEPI_{it-1} + \delta_{1\,12it}LGHG_{it-1} + \delta_{1\,13it}LEEI_{it-1} \\
& + \delta_{1\,14it}LCOAL_{it-1} + \delta_{1\,15it}LOIL_{it-1} + \alpha_{2t}SD2008 + \varepsilon_{1it}
\end{aligned}
\tag{3}
$$

The equation with $\Delta LEEI_{it}$ as dependent, and the equation with $\Delta LIPI_{it}$ as dependent are equation (2) and (3) respectively. The operator "Δ" indicates the first differences, and the operator "L" indicates de natural logarithm of the variable. The $\alpha_{1t}$ indicates the constant, $\beta_{keit}$, k= 1, 2 and e=1,.., m indicates the short-run coefficients, $\delta_{keit}$, k= 1, 2 and e=1,.., m indicates the long-run coefficients.

The ARDL is a robust and conclusive method of analyses allowing to verify a presence of cointegration. The literature regarding cointegration as changed emerging new methods and techniques. The nonlinear cointegration approach leads to a more focused analysis, allowing to evaluate the variables in different points. The linking between nonlinear and linear ARDL approach is performed in the following section.

## 3.4 Asymmetries and Nonlinearity

Asymmetries are the positive and negative changes of the variables. Schorderet & Yann, (2001) uses this base notion to define and structure the nonlinearity concept. Indicating that the existing volatility of the explanatory variables reflects different effects in the dependent variable. This concept emerges a new and important method of analysis revealing hidden relationships between the variables in different moments and forms.

The concept of nonlinearity has been implemented in the following equation by Schorderet & Yann, (2001)

$$x_t = \alpha^+ y_t^+ + \alpha^- y_t^- + \epsilon_t \tag{4}$$

In equation (4) $y_t$ is decomposed as $y_t = y_t^+ + y_t^- + y_0$ , where $y_t^+$ are $y_t^-$ are partial sum processes of positive and negative changes in $y_t$ respectively. The sum process is identified in the following equations (5 and 6):

$$y_t^+ = \sum_{n=1}^{t} \Delta y_n^+ = \sum_{n=1}^{t} \max\,[y_n\,, 0] \tag{5}$$

$$y_t^- = \sum_{n=1}^{t} \Delta y_n^- = \sum_{n=1}^{t} \min\,[y_n\,, 0] \tag{6}$$

The use of this summing process can only be performed if the used variables are integrated of order one *I(1)* since the series has to be stationary in first differences. Granger & Yoon, (2002) developed this concept and identified cointegration between the ascending and descending variables. The use of such technique allows to verify the effect of the volatility of the explaining variable in the dependent variable separately. Schorderet, (2003) generalises the “hidden cointegration” with the following long-run equation.

$$z_t = \alpha^+ y_0^+ + \alpha^- y_0^- + \delta^- y_1^- + \delta^+ y_1^+ \tag{7}$$

$y_t$ is considered asymmetric cointegrated if $z_t$ is stationary. Short-run symmetric can also be analyzed with the constringent of $\delta^+ = \delta^-$, where $\delta$ indicates the short-run coefficient. Long-run multipliers (elasticities) are calculated using the following equations:

$$\alpha^+ = -\frac{\alpha_1^+}{\rho} \tag{8}$$

$$\alpha^- = -\frac{\alpha_1^-}{\rho} \tag{9}$$

To test for the presence of long run symmetry the Wald test is performed, $\alpha^{+} = \alpha^{-}$. The null hypothesis is a symmetric relationship, indicating. that the decomposition of the variable is not suitable (Chattopadhyay & Kumar Mitra, 2015), obtaining the $x^2$, indicating the signification level.

To analyse a presence of “hidden cointegration,” it is required a long-run equation (ECM). The ARDL model meets the necessary requirements, by allowing to estimate a long-run equation. This way is possible to include the non-linearity concept within the ARDL method, emerging the nonlinear ARDL.

## 3.5 Nonlinear Autoregressive Distributed Lag model

The nonlinear ARDL model is proposed by Shin, Yu and Greenwood-Nimmo, (2014). This method merges the hidden cointegration concept with the standard linear ARDL method. The ARDL model meets the necessary requirements to merge the hidden cointegration analyses since the dependent variable must be stationary in first differences and allows to obtain a long-run coefficient. Keeping in mind that all the referenced properties of the ARDL can also be applied in the NARDL.

The NARDL method allows a more efficient analysis since all variables are subjected to volatility, and the NARDL can measure and analyses the variable in four different moments, instead of the ARDL that only allows to analyses the variable in two moments. The NARDL allows to analyze the independent variable in four different moments. Both in short and long run, and simultaneously the ascending and descending movement of the variable, allowing to obtain the various signs in the different moments of analyses. In the current literature, it is possible to verify the implementation of this new methodology (Bildirici & Ozaksoy, 2017; Chattopadhyay & Kumar Mitra, 2015; Kumar, 2017; Lahiani, Hammoudeh, & Gupta, 2016; Tang & Bethencourt, 2017). The obtained coefficients and ECM have the same interpretation as the ARDL model (Atil, Lahiani, & Nguyen, 2014). In the NARDL model, the asymmetric error correction mechanism (AECM) is comprised between [-1, 0] and must be statistically significant. The obtained estimations are represented as follows:

$$\begin{aligned}\Delta LEEI_{it} = {} & \alpha_{1t} + \sum_{n=0}^{k} \beta_{1\,2\mathrm{it}} \Delta LI^{+}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,3it} \Delta LGHG^{+}{}_{it-n} \\ & + \sum_{n=0}^{k} \beta_{1\,4it} \Delta LGHG^{-}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,4it} \Delta LIPI^{+}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,4it} \Delta LIPI^{-}{}_{it-n} \\ & + \sum_{n=0}^{k} \beta_{1\,6it} \Delta LCOAL_{it-n} + \sum_{n=0}^{k} \beta_{1\,7it} \Delta LRES_{it-n} + \delta_{1\,8it} LEEI_{it-1} \\ & + \delta_{1\,9it} LIPI^{+}{}_{it-1} + \delta_{1\,10it} LIPI^{-}{}_{it-1} + \delta_{1\,11it} LI^{+}{}_{it-1} + \delta_{1\,12it} LI^{-}{}_{it-1} \\ & + \delta_{1\,13it} LGHG^{+}{}_{it-1} + \delta_{1\,14it} LIEPI^{-}{}_{it-1} + \alpha_{2t} TREND + \varepsilon_{1it}\end{aligned} \tag{10}$$

$$\begin{aligned}\Delta LIPI_{it} = {} & \alpha_{1t} + \sum_{n=0}^{k} \beta_{1\,2it} \Delta LI^{+}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,3it} \Delta LI^{-}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,4it} \Delta LGHG^{+}{}_{it-n} \\ & + \sum_{n=0}^{k} \beta_{1\,5it} \Delta LGHG^{-}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,6it} \Delta LIEPI^{-}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,7it} \Delta LEEI^{-}{}_{it-n} \\ & + \sum_{n=0}^{k} \beta_{1\,8it} \Delta LEEI^{+}{}_{it-n} + \sum_{n=0}^{k} \beta_{1\,9it} \Delta LOIL_{it-n} + \sum_{n=0}^{k} \beta_{1\,10it} \Delta LEMP_{R\,it-n} \\ & + \sum_{n=0}^{k} \beta_{1\,11it} \Delta LCOAL_{it-n} + \sum_{n=0}^{k} \beta_{1\,12it} \Delta HYDRO_{it-n} + \delta_{1\,13it} LIPI_{it-1} \\ & + \delta_{1\,14it} LEEI^{+}{}_{it-1} + \delta_{1\,15it} LEEI^{-}{}_{it-1} + \delta_{1\,16it} LI^{-}{}_{it-1} \\ & + \delta_{1\,17it} LGHG^{-}{}_{it-1} + \delta_{1\,17it} LGHG^{+}{}_{it-1} + \delta_{1\,17it} LOIL_{it-1} \\ & + \delta_{1\,17it} LCOAL_{it-1} + \delta_{1\,17it} LHYDRO_{it-1} + \varepsilon_{1it}\end{aligned} \tag{11}$$

The equation with $\Delta LEEI_{it}$ as dependent, and the equation with $\Delta LIPI_{it}$ as dependent are equation (10) and (11) respectively. The operator "Δ" indicates the first differences, and the operator "*L*" indicates de natural logarithm of the variable. The $\alpha_{1t}$ indicates the constant, $\beta_{keit}$, *k*= 1, 2 and *e*=1,.., *m* indicates the short-run coefficients, $\delta_{keit}$, *k*= 1, 2 and *e*=1,.., *m* indicates the long-run coefficients. The symbols "+" and "-" indicates the positives and negatives changes respectively.

The NARDL method allows to perform different cointegration tests such as the bounds tests (Shin et al., 2014), and the *T*-test proposed by Banerjee, Dolado, & Mestre, (1998). Both referenced tests cannot be performed under a panel analyses due to lack of critical values. However, the presence of an AECM by itself indicates a presence of a long-run relationship and explanatory capacity. To confirm correct properties of the obtained model and the presence of the "hidden cointegration," the long-run symmetries tests are implemented.

## 4. Results

Following the path defined in the methodology section, firstly the correlation matrix was examined to ensure that none of the variables could skew the results due to high correlations. In the correlation matrix, the higher value found is 0.71, mitigating the presence of collinearity. To strengthen the results obtained in the correlation matrix the Variance Inflation Factor (VIF) (table A.1) was performed, revealing values inferior of 10. Indicating that there is no concern regarding collinearity since the VIF value is in the range of acceptance (Hair, 1992). As referenced in the literature, the ARDL model and NARDL allows the inclusion of “0” and “1” dummies. To correct the European financial crisis a stability dummy starting in 2008 to the end of the period is used, an impulse dummy in 2004 is also used to correct the existing outlier.

Table 2 - Correlation Matrix

| | *LEEI* | *LIPI* | *LI* | *LGHG* | *LIEPI* | $LEMP_R$ | *LRES* | *LHYDRO* | *LOIL* | *LCOAL* | $LGDP_{PC}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *LEEI* | 1 | | | | | | | | | | |
| *LIPI* | 0.0811 | 1 | | | | | | | | | |
| *LI* | -0.1402 | 0.0605 | 1 | | | | | | | | |
| *LGHG* | -0.2543 | 0.131 | 0.7029 | 1 | | | | | | | |
| *LIEPI* | 0.1644 | 0.5052 | -0.0321 | -0.1333 | 1 | | | | | | |
| $LEMP_R$ | 0.3185 | -0.1508 | 0.3136 | -0.0746 | -0.359 | 1 | | | | | |
| *LRES* | 0.4602 | 0.4845 | -0.3725 | -0.3007 | 0.7161 | -0.2902 | 1 | | | | |
| *LHYDRO* | 0.1934 | 0.2258 | -0.2008 | -0.2638 | -0.0323 | 0.4284 | 0.2068 | 1 | | | |
| *LOIL* | -0.0896 | 0.1982 | -0.3018 | 0.055 | -0.1689 | 0.0909 | 0.0427 | 0.3084 | 1 | | |
| *LCOAL* | 0.2619 | -0.3493 | 0.2937 | 0.1696 | -0.2408 | 0.42 | -0.1785 | -0.3346 | -0.1043 | 1 | |
| $LGDP_{PC}$ | 0.0808 | -0.1278 | 0.5531 | -0.1665 | 0.0788 | 0.416 | -0.1553 | -0.1422 | -0.5953 | 0.2783 | 1 |

Secondly, the unit roots tests were performed. The obtained results are displayed in Table A.1; the first-generation unit root tests reveal that all variables are stationary in first differences. In Table 3, the individual cross section dependence test, proposed by Pesaran, (2004) can be appraised. The presence of individual cross-section dependence indicates that the second-generation unit root tests must be carried out. The obtained results (Table A.2) indicate that none of the used variables are integrated of order 2 (I(2)).

Table 3 – Individual cross section dependence

| Variable | | Variable | | Variable | |
|---|---|---|---|---|---|
| $LEEI$ | 22.17*** | $LIPI$ | 5.28*** | $LI$ | 12.04*** |
| $\Delta LEEI$ | 3.18*** | $\Delta LIPI$ | 24.1*** | $\Delta LI$ | 18.36*** |
| $LEEI^{+}$ | 28.46*** | $LIPI^{+}$ | 28.54*** | $LI^{+}$ | 27.99*** |
| $\Delta LEEI^{+}$ | 1.82* | $\Delta LIPI^{+}$ | 17.34*** | $\Delta LI^{+}$ | 14.18*** |
| $LEEI^{-}$ | 22.18*** | $LIPI^{-}$ | 28.97*** | $LI^{-}$ | 26.71*** |
| $\Delta LEEI^{-}$ | 3.39*** | $\Delta LIPI^{-}$ | 27.21*** | $\Delta LI^{-}$ | 17.81*** |
| $LIEPI$ | 27.94*** | $LRES$ | 27.18*** | $LGDP_{PC}$ | 23.12*** |
| $\Delta LIEPI$ | 18.16*** | $\Delta LRES$ | 3.8*** | $\Delta LGDP_{PC}$ | 22.25*** |
| $LIEPI^{+}$ | 28.97*** | $LOIL$ | 16.23*** | $LGHG$ | 18.26*** |
| $\Delta LIEPI^{+}$ | 16.87*** | $\Delta LOIL$ | 2.5*** | $\Delta LGHG$ | 11.38*** |
| $LIEPI^{-}$ | 24.68*** | $LEMP_{R}$ | 22.47*** | $LGHG^{+}$ | 25.34*** |
| $\Delta LIEPI^{-}$ | 11.56*** | $\Delta LEMP_{R}$ | 5.57*** | $\Delta LGHG^{+}$ | 9.27*** |
| $LCOAL$ | 8.7*** | $LHYDRO$ | 9.33*** | $LGHG^{-}$ | 28.5*** |
| $\Delta LCOAL$ | 2.39*** | $\Delta LHYDRO$ | 7.34*** | $\Delta LGHG^{-}$ | 11.2*** |

Notes: *** significates 1% of significance

The obtained results reveal that none of the used variables is *I(2)*, allowing the implementation of the ARDL and NARDL model. Continuing on the same path as referred, the Hausman test using sigmamore and sigmaless options was performed (Fuinhas, Marques, & Couto, 2015; Levie & Autio, 2008), the confrontation between random effects and fixed effects (Table 4) reveals that fixed effects are present. Concerning the obtained results further, testing is needed to identify the proper estimator. The proposed cross-section dependence test reveals the presence of cross-section dependence. (table 4).

Table 4 – Diagnostic Tests

| | ARDL | | NARDL | |
|---|---|---|---|---|
| | ΔLEEI | ΔLIPI | ΔLEEI | ΔLIPI |
| Hausman | [26.87] | [27.81] | [64.32***] | [28.16] |
| Hausman, Sigmamore | [25.58***] | [24.72***] | [46.96***] | [24.49***] |
| Hausman, Sigmaless | [28.68***] | [27.54***] | [64.66***] | [27.41***] |
| Pesaran test | {-1.253} | {5.905***} | {-0.91} | {2.673***} |
| Breusch-Pagan LM test | [79.26**] | [91.369***] | [70.118*] | [57.317] |
| Wooldridge test | (46.546***) | (19.308***) | (35.67***) | (16.091***) |
| Modified Wald test | [26.38***] | [17.33*] | [18.32*] | [21**] |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively; in (.) F-Statistic values; in [.] the $\chi^2$ value; in {.} $N(\mu , \sigma^2)$; Hausman indicates the Hausman test; Pesaran test and Breusch-Pagan LM test indicates the cross-section dependence test; Wooldridge test indicates the first order serial correlation test; Modified Wald test indicates the heteroskedasticity test.

Firstly, it was checked the presence of first-order serial correlation (Table 4) and heteroskedasticity test (Table 4). The results of both tests reveal the presence of serial correlation and heteroskedasticity. Taking account all the obtained results the Driscoll-Kraay estimator reveals to be the most suitable.

According to all diagnostic tests, the models were estimated using the Driscoll-Kraay estimator compiled with the ARDL and NARDL models (Table 5).

Table 5 – ARDL and NARDL estimations

| | ARDL | | NARDL | |
|---|---|---|---|---|
| | *ΔLEEI* | *ΔLIPI* | *ΔLEEI* | *ΔLIPI* |
| *ΔLEEI* | | .2860946*** | | |
| $\Delta LEEI^{+}$ | | | | .2706993*** |
| $\Delta LEEI^{-}$ | | | | .468547*** |
| *ΔLIPI* | .448952*** | | | |
| $\Delta LIPI^{+}$ | | | .5661094*** | |
| $\Delta LIPI^{-}$ | | | .3236627*** | |
| *ΔLGHG* | -.6306435*** | .7682048*** | | |
| $\Delta LGHG^{+}$ | | | -.6339313*** | .6922022*** |
| $\Delta LGHG^{-}$ | | | -.5105838*** | .8584517*** |
| *ΔLI* | | .3250991*** | | |
| $\Delta LI^{+}$ | | | .1485202* | .214822*** |
| $\Delta LI^{-}$ | | | | .3804492*** |
| *ΔLIEPI* | | .1754821** | | |
| $\Delta LIEPI^{-}$ | | | | .4650646*** |
| $\Delta LEMP_{R}$ | | .1328845* | | .203776*** |
| *ΔLHYDRO* | | .0228447** | | .0282669** |
| *ΔLCOAL* | .0529903*** | -.0857807*** | .0489163*** | -.0826522*** |
| *ΔLRES* | .0481812** | | .0604328*** | |
| *ΔLOIL* | | -.016327* | | -.0167135* |
| *LEEI(-1)* | -.206376*** | .1044854*** | -.3929737*** | |
| $LEEI^{+}(-1)$ | | | | .0867543*** |
| $LEEI^{-}(-1)$ | | | | .241662*** |
| *LIPI(-1)* | .1395989*** | -.2044905*** | | -.2133767*** |
| $LIPI^{+}(-1)$ | | | .2652338*** | |
| $LIPI^{-}(-1)$ | | | .1053734*** | |
| *LGHG(-1)* | -.1377382** | .2079228** | | |
| $LGHG^{+}(-1)$ | | | -.3020065*** | .3862619*** |
| $LGHG^{-}(-1)$ | | | | .3388042** |
| $LI^{+}(-1)$ | | | .2126154*** | |
| $LI^{-}(-1)$ | | | -.1463841*** | -.1348242** |
| *LIEPI(-1)* | .0889153** | .0641015*** | | |
| $LIEPI^{-}(-1)$ | | | .5189499*** | |
| *LHYDRO(-1)* | | | | .018531* |
| *LCOAL(-1)* | | -.0596344*** | | -.0761147*** |
| *LOIL(-1)* | .0142233* | -.0132706* | | -.0107945* |
| *ID2004* | .0076121* | | | |
| *SD2008* | | -.0247968* | | |
| *C* | -1.290014*** | 0.222639 | -2.018585*** | 1.199417*** |
| TREND | | | .003562*** | |
| ECM/AECM | -.206376*** | -.2044905*** | -.3929737*** | -.2133767*** |
| | | | | |
| Obs | 176 | 176 | 176 | 176 |
| F-OBS | (100.87***) | (1166.94***) | (1198.55***) | (21.76***) |
| $R^2$ | 0.436 | 0.7598 | 0.5658 | 0.7934 |
| $VIF_{MEAN}$ | 1.54 | 1.53 | 2.38 | 2.4 |
| $WSR_{GHG}$ | | | [0.73] | [0.83] |
| $WSR_{IPI}$ | | | [13.92***] | |
| $WSR_{EEI}$ | | | | [0.93] |
| $WSR_{I}$ | | | | [2.24] |
| $WLR_{IPI}$ | | | [7.81***] | |
| $WLR_{I}$ | | | [37.97***] | |
| $WLR_{GHG}$ | | | | [2.43] |
| $WLR_{EEI}$ | | | | [4.93**] |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively; F indicates the F test with $H_0$ of non-significance of the estimated parameters, (.) F-Statistic values; $W_{SR}$ and $W_{LR}$ indicate the short and long run symmetry with $H_0$ of symmetric relationship, in [.] the $\chi^2$ value; $VIF_{MEAN}$ mean values of the variance inflation statistic.

The obtained error correction mechanism (ECM) and asymmetric error correction mechanism (AECM) is comprised between [-1, 0] and statistically significant, as showed in Table 5. The NARDL symmetry indicates that is proper to perform the NARDL because the null hypothesis of symmetry is rejected, indicating the presence of asymmetries.

Confronting both methodologies significant changes can be appraised. In the ARDL model an expected relationship could not be proven, a long-run relationship of investment in the IPI model. Although using the NARDL model such relationship is obtained. Confronting also the obtained ECM (-0.20) in the EEI model is possible to verify an augmentation of the AECM (-0.39) indicating that the model has the more explanatory capacity.

The EEI model demonstrates expected results, economic growth is pushing the economy towards efficiency, even when there is a slowdown in economic growth as indicate by the positive sing in $LIPI^{-}$. The increase of investment ($LI^{+}$) influences positively the Δ*LEEI*, the decrease ($LI^{-}$) results in negative influence in the efficiency. The Industry energy prices index (*LIEPI*) leads to a more efficiency economy, the presence of a price leads the agents to a more rational use in order to reduce the energy expenditures. The electricity production form *RES* and *LCOAL*, influences positively the energy efficiency. Linking the both methodologies in the ARDL model the obtained results are in concordance, the *LI* variable deserves a special comment since in the ARDL is not possible to establish a relationship, in the NARDL model the long-run relation is established where a slow down our decrease of the investment ($LI^{-}$) results in opposite results, contributing negatively to the energy efficiency. This output and difference justifies the use the NARDL model as the central methodology.

In the IPI model, the obtained results indicate that the energy efficiency is incremating the economic growth both in descending ($LEEI^{-}$), and ascending ($LEEI^{+}$) moment. This result shows that using energy in an efficient way leads to more production using less resources, overall is proved a bidirectional relationship between *IPI* and *EEI* (feedback hypothesis).

As expected the raising of investment ($\Delta LI^{+}$) leads to higher economy growth, and the decremental ($LI^{-}$) constrains the economic growth. The *GHG* are positive correlated with economic growth ($\Delta LGHG^{+}, \Delta LGHG^{-}, LGHG^{+}$ and $LGHG^{-}$), these results is expected since $CO_2$ are incorporated in the *GHG*. Such positive relationship is well documented in the current literature. In the ARDL model the *LEEI*, influences positively the economic growth still in the NARDL model the $LEEI^{+}$ influences positively the economic growth. Overall the ARDL models allows conclusive and robust results, still the use the NARDL allows a more convincing and detailed results.

The elasticities were computed using the long-run coefficient divided by ECM/AECM and multiplied by (-1). The obtained results and the signification levels can be appraised in Table 6.

Table 6 - Elasticities

| | ARDL | | NARDL | |
|---|---|---|---|---|
| | *ΔLEEI* | *ΔLIPI* | *ΔLEEI* | *ΔLIPI* |
| *LEEI(-1)* | | .510955*** | | |
| $LEEI^{+}(-1)$ | | | | 0.406578 |
| $LEEI^{-}(-1)$ | | | | 1.132561 |
| *LIPI(-1)* | .6764298*** | | | |
| $LIPI^{+}(-1)$ | | | .6749402*** | |
| $LIPI^{-}(-1)$ | | | .2681436*** | |
| *LGHG(-1)* | -.6674135*** | 1.016785*** | | |
| $LGHG^{+}(-1)$ | | | -.7685157*** | 1.810235*** |
| $LGHG^{-}(-1)$ | | | | 1.587822*** |
| $LI^{+}(-1)$ | | | .5410424*** | |
| $LI^{-}(-1)$ | | | -.3725037*** | -.6318601*** |
| *LIEPI(-1)* | .4308412*** | .3134695*** | | |
| $LIEPI^{-}(-1)$ | | | 1.320572*** | |
| *LHYDRO(-1)* | | | | .0868463** |
| *LCOAL(-1)* | | -.2916245*** | | -.3567151*** |
| *LOIL(-1)* | .0689192* | -.0648961*** | | -.0505888** |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively

The obtained results indicate that all elasticities are significant at least at 10%. The elasticities show in percentage the effect that the independent variables has in the dependent variable. As an example, $LIPI^{+}(-1)$ increases in 1%, reflects circa 0.67% in the *ΔLEEI*.

## 5. Robustness check

In this section, one explores the relationship between economic growth, greenhouse gases and energy efficiency through the Environmental Kuznets curve. Both *GDP* per capita and Industrial production index are used separately creating a comparison point.

Following the same path as described in the methodology section, is verified through the unit root tests (Table A.2), that none of the used variables are integrated of order 2. The Hausman test reveals the presence of fixed effects (Table 7). Is also verified the presence of Cross-section Dependence (Pesaran, 2004), heteroskedasticity (Greene, 2000) and First order serial correlation (Wooldridge, 2002). The obtained results (Table 7) indicate the presence of first-order serial correlation, heteroscedasticity and cross section dependence, pointing out that the Driscoll-Kraay is the proper estimator to use.

Table 7 – Diagnostic Tests

| | $\Delta LGHG_{IPI}$ | $\Delta LGHG_{GDP}$ |
|---|---|---|
| Hausman | [44.6***] | [97.19***] |
| Hausman, Sigmamore | [37.54***] | [52.8***] |
| Hausman, Sigmaless | [46.12***] | [74.29***] |
| Pesaran test | {3.389***} | {5.095***} |
| Wooldridge test | (45.748***) | (56.859***) |
| Modified Wald test | [129.93***] | [102.89***] |

Notes: *** denotes 1% of significance; in (.) F-Statistic values; in [.] the $\chi^2$ value; in {.} $N(\mu , \sigma^2)$; Hausman indicates the Hausman test; Pesaran test indicates the cross-section dependence test; Wooldridge test indicates the first order serial correlation test; Modified Wald test indicates the heteroskedasticity test.

Using the ARDL methodology two models were estimated, following the current literature (Zoundi, 2017) the *GDP* was converted in per capita values and squared. The obtained results can be appraised in Table 8. As expected both $LGDP^2_{PC}$ and $LIPI^2$ are negative and statistically significant. The obtained ECM it is also comprised between [-1, 0] and is statistically significant.

Table 8 – EKC Estimations

| | $\Delta LGHG_{IPI}$ | $\Delta LGHG_{GDP}$ |
|---|---|---|
| *ΔLEEI* | -.2708352*** | -.2139136*** |
| $\Delta LIPI^2$ | .0426585*** | |
| $\Delta LGDP_{PC}$ | | .69585*** |
| $\Delta LEMP_R$ | | .1434007* |
| *ΔLRES* | -.0376843*** | -.0256561** |
| *ΔLHYDRO* | -.0612239*** | -.0586708*** |
| *LGHG(-1)* | -.4120617*** | -.5906393*** |
| *LIPI(-1)* | 1.132297* | |
| $LIPI^2(-1)$ | -.1171042* | |
| $LGDP_{PC}(-1)$ | | 1.062888*** |
| $LGDP^2_{PC}(-1)$ | | -.0340854*** |
| *LI(-1)* | | -.0418813** |
| $LEMP_R(-1)$ | .1253044** | .1848884*** |
| *LIEPI(-1)* | | -.1017355* |
| *LRES(-1)* | -.0282114*** | -.0279414*** |
| *LHYDRO(-1)* | -.0529304** | -.0592922*** |
| *C* | -0.76347 | -3.0864*** |
| *ECM* | -.4120617*** | -.5906393*** |
| *Obs* | 176 | 176 |
| *F-obs* | [47.06***] | [175.85***] |
| $R^2$ | 0.6242 | 0.5974 |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively; F indicates the F test with $H_0$ of non-significance of the estimated parameters, (.) F-Statistic values;

The use of IPI allows to enrich the literature and proves that IPI as the ability to produce quality and robustness results as the *GDP*. Therefore, the use of the classic version of EKC using the *GDP*, and has an alternative using the *IPI*. The obtained results show a concordance between the classic EKC and the alternative using the *IPI*. Using the long-run coefficients, the elasticities were computed and compiled in Table 9.

Table 9 - Elasticities

| | $DLGHG_{IPI}$ | $DLGHG_{GDP}$ |
|---|---|---|
| *LIPI(-1)* | 2.747883** | |
| $LIPI^2(-1)$ | -.2841909* | |
| $LGDP_{PC}(-1)$ | | 1.799555*** |
| $LGDP^2_{PC}(-1)$ | | -.0577093*** |
| *LI(-1)* | | -.0709084** |
| $LEMP_R(-1)$ | .3040915*** | .313031*** |
| *LIEPI(-1)* | | -.1722464** |
| *LRES(-1)* | -.0684641*** | -.047307*** |
| *LHYDRO(-1)* | -.1284525*** | -.1003864*** |

Notes: ***, ** denotes 1% and 5% of significance respectively

The turning point was also computed, and results are compiled in Table 10. This point indicates the maximum of the *GHG* emissions, before the descending and creating the inverted U-shape curve. Both in IPI and *GDP* model was possible to obtain the negative sign indicating the presence of the EKC. Still, the Turning point value is different. Indeed, a direct comparison cannot be made since the *GDP* includes all the economic activity of the country, and the *IPI* represents economic growth but only includes the industrial activity.

Table 10 – Turning Point

| | $\Delta$LGHG $_{IPI}$ | $\Delta$LGHG $_{GDP}$ |
|---|---|---|
| *T** | 4.834573*** | 15.59156*** |

Notes: *** denotes 1% of significance

The turning point is calculated using the modified Wald test using the following equations (Brown & McDonough, 2016):

$$T^{*} = -(\,L\,IPI\;(-1)/2\;LIPI\;(-1)^{2}) \tag{12}$$

$$T^{*} = -(\,LGDP_{PC}\;(-1)/2\;LGDP_{PC}\;(-1)^{2}) \tag{13}$$

Since all variables are used in logarithm form, is necessary the following transformation (Sencer Atasoy, 2017):

$$T = e^{T^{*}} \tag{14}$$

The turning point references the point where the GHG emissions decoupling from economic growth. Implementing the equation (12) and (13) and converting to real values using the equation (14) it was possible to obtain the Turing point. The Industrial production index, reveals the value of 125,7, with the significance of 1%. The IPI variable reveals to be suitable in the EKC estimation. Regarding the $GDP_{PC}$, a high and non-statistical significant value is obtained. This result is known on the current literature, authors such as Bouznit & Pablo-Romero, (2016); Dong, Wang, & Guo, (2016), Holtz-Eakin & Selden, (1995), Liddle, (2004) and Richmond & Kaufmann, (2006), encountered high values and outside of the sample range. The use of a panel approach and the use of the GHG emissions hardens the possibility to achieve a robust turning point. Since the used countries have different growth rates.

The GHG comprises all the greenhouse gases, the literature focuses mainly in $CO_2$, $SO_x$ and $NO_x$ (Danesh Miah, Farhad Hossain Masum, & Koike, 2010), therefor to achieve the turning point is required a higher effort from the economy. Such limitations must be considered in future researches. The use a specific country and a specific greenhouse gas can allow a more robust and conclusive results.

# 6. Discussion

Energy efficiency has become a major theme among all countries and international institutions. This work indicates and demonstrates the principal components to promote such efficiency without neglecting the economy growth. The presence of such concept leads to greater economic growth. Energy efficiency leads to more production using fewer resources. Even when there is a slowdown in efficiency allows the economy to produce more with fewer costs.

Economic growth is pushing the economy towards energy efficiency. Policymakers must create and adapt the existing polices to accentuate the growing path of energy efficiency. In the case of recession or slowdown by 1% the economic growth contributes to 0,26% of energy efficiency. In the event of economic prosperity, the influence doubles the value influencing in 0,67%.

The investment also represents an important role in promoting energy efficacy. The raising of investment influences positively economic growth and energy efficiency. The asymmetric effect is observed in the case of decrease of the investment. The reduce of investment forces the economy to begin the growth path from a lower position. Requiring to double de effort to achieve the same point before the slowdown. The investment also leads to sustainable growth influencing negatively the *GHG*, which could suggest that the investors are interested in the sustainability of the economies.

The Greenhouse gases are positively correlated with economic growth and negatively correlated with energy efficiency. Those findings should inspire policymakers to develop measures with the ability to reduce environmental degradation without compromising the economic growth and simultaneously increasing energy efficiency. To achieve such goal, alternative electricity sources such as *RES* having the ability to reduce *GHG* emissions and increasing energy efficiency. The *HYDRO* source also reveals the ability to reduce *GHG* emissions, and simultaneously increase the economic growth.

The energy pricing, reveals to be one of the most important mechanisms to control economic growth, energy efficiency and environmental degradation. Lowering the energy prices will result in more production in the short-run. On the long-run, the presence of the price will force the rational use of energy. The energy consumption will result in expenses to the industrial sector, to minimize such cost the industries will search alternatives ways to produce our reduce consumption of energy. In one hand, if the energy expenses were equal to zero, the industry would have no incentives to invest and development technology with lower energy consumption.

The pricing mechanism incorporates the concept of demand-side management (DSM). DSM is the ability to change the consumer habits, and the energy pricing falls in such context. Real time prices would force the consumer to reduce their consumption during peak load times to obtain an inferior price of energy. The presence of such prices leads to a more rational use of energy. Policymakers must incorporate and develop a real-time energy pricing mechanism that they change according with the demand forcing the consumer to change their habits to minimize their costs.

The European Union economies are running towards the sustainable growth with the maximization of energy efficiency. The EKC indicates that the applied policies are leading the economies towards the desired path of sustainable growth. Still, those mechanisms need constant improvement to avoid a rebound effect which could force the economies to start from a lower position of efficiency requiring a redoubled effort to achieve the previous point of efficiency.

Economic growth without increasing the *GHG* emissions can only be established after the turning point conventional indicated by the EKC. In the literature, a consensus regarding the turning point cannot be found. Many authors identified different turning points according to the different greenhouse gases. Still, such point can also be established throw cooperation between different countries, institutions and governments. Policymakers must foment such relationships to obtain practical guidelines of policies already established and tested in order countries.

Merging all the indicate components can lead the economies to a rapid and sustainable growth. Countries must find a way to increase the investment by the business sector, and simultaneously invest in renewable sources, and regulate the energy prices to avoid waste of energy and constraining the economic growth. The optimization of such components and with the “natural” path of energy efficiency promoted by the economic growth the economies will be able to achieve rapid growth.

Energy efficiency still needs more development, the maximization of the use of resources is desirable. Energy loses will always be present, new technologies such as smart grids have the ability to reduce the existing loses. Still, it will not be able to mitigate them.

# 7. Conclusion

This work focuses on analysing the energy efficiency in the industrial sector, for 11 European countries for the time span of 1997 till 2013. The used methodology concentrates in the nonlinear ARDL that allows the distinction of short and long run and allows to incorporate the volatility of the independent variables. The obtained results are in concordance with the current literature; the economic growth is pushing the economy towards energy efficiency and simultaneously reducing the *GHG* emissions.

The investment plays a major role in the energy efficiency leading the economy towards efficiency. Still, the decoupling between economic growth and *GHG* has yet been achieved. Policymakers need to improve current energy efficiency, and environmental policies to the economy reach the desired sustainable and efficient growth. To do so, a critical component is the presence of energy prices, which forces the consumer to change their habits. The DSM will play a major role in energy efficiency, and policy makers must focus their efforts on developing policies that influence both consumers and producers of energy to maximise their resources and avoid wasting energy.

For further research, a large time span is desired. Country-specific analyses can also generate more detailed analyses permitting policymakers to generate country-specific policies. Each country faces a different reality: having a different industry specification (i), geography(ii), population (iii), sources of electricity production (iv); electricity grids (v), investment capacity (vi) and natural resources (vii). Requirement custom policies to accommodate such differences.

The incorporation of policies variables allows to verify the efficiency of each applied policies. Given that the economies have to their disposal several sources of energy can also be suitable to analyse which sources reveals to be more environmentally friendly and with higher rates of efficiency.

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# Appendix

A.1 - Variance inflation factor

| | ARDL | | NARDL | |
|---|---|---|---|---|
| | $\Delta LEEI$ | $\Delta LIPI$ | $\Delta LEEI$ | $\Delta LIPI$ |
| $\Delta LEEI$ | | 1.65 | | |
| $\Delta LEEI^{+}$ | | | | 1.92 |
| $\Delta LEEI^{-}$ | | | | 1.35 |
| $\Delta LIPI$ | 1.76 | | | |
| $\Delta LIPI^{+}$ | | | 1.76 | |
| $\Delta LIPI^{-}$ | | | 1.63 | |
| $\Delta LGHG$ | 2.18 | 2.11 | | |
| $\Delta LGHG^{+}$ | | | 1.55 | 1.68 |
| $\Delta LGHG^{-}$ | | | 2.18 | 2.12 |
| $\Delta LI$ | | 1.87 | | |
| $\Delta LI^{+}$ | | | 1.61 | 1.67 |
| $\Delta LI^{-}$ | | | | 2.07 |
| $\Delta LIEPI$ | | 1.13 | | |
| $\Delta LIEPI^{-}$ | | | | 1.34 |
| $\Delta LEMP_R$ | | 1.36 | | 1.42 |
| $\Delta LHYDRO$ | | 1.15 | | 1.18 |
| $\Delta LCOAL$ | 1.64 | 1.7 | 1.7 | 1.86 |
| $\Delta LRES$ | 1.14 | | 1.16 | |
| $\Delta LOIL$ | | 1.09 | | 1.11 |
| $LEEI(-1)$ | 1.11 | 1.34 | 1.87 | |
| $LEEI^{+}(-1)$ | | | | 2.87 |
| $LEEI^{-}(-1)$ | | | | 3.14 |
| $LIPI(-1)$ | 1.91 | 2.09 | | 1.71 |
| $LIPI^{+}(-1)$ | | | 4.53 | |
| $LIPI^{-}(-1)$ | | | 3.59 | |
| $LGHG(-1)$ | 1.26 | 1.34 | | |
| $LGHG^{+}(-1)$ | | | 1.92 | 4.35 |
| $LGHG^{-}(-1)$ | | | | 6.9 |
| $LI^{+}(-1)$ | | | 4.23 | |
| $LI^{-}(-1)$ | | | 3.51 | 4.73 |
| $LIEPI(-1)$ | 1.66 | 1.82 | | |
| $LIEPI^{-}(-1)$ | | | 2.14 | |
| $LHYDRO(-1)$ | | | | 1.91 |
| $LCOAL(-1)$ | | 1.56 | | 2.22 |
| $LRES(-1)$ | | | | |
| $LOIL(-1)$ | 1.18 | 1.21 | | 2.37 |

A.2 – Unit Roots test

| | | | $LEEI$ | $\Delta LEEI$ | $LEEI^+$ | $\Delta LEEI^+$ | $LEEI^-$ | $\Delta LEEI^-$ | $LIPI$ | $\Delta LIPI$ | $LIPI^+$ | $\Delta LIPI^+$ | $LIPI^-$ | $\Delta LIPI^-$ | $LI$ | $\Delta LI$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *LC* | *a)* | | 0.86055 | -2.57114*** | 0.16003 | -3.44874*** | 0.72181 | -3.00399*** | -4.71394*** | -8.27979*** | -2.99500*** | -7.10164*** | -2.26349** | -6.54955*** | -1.91011** | -7.60151*** |
| | *b)* | | -0.94226 | -4.01417*** | -0.03922 | -4.79153*** | 0.20781 | -2.77618*** | -1.74330** | -8.71257*** | -1.88710** | -7.96534*** | 3.28351 | -6.45668*** | -2.06455** | -7.10940*** |
| | *c)* | | -4.52674*** | -6.45915*** | 4.33904 | -5.2479*** | 3.5786 | -5.09178*** | 1.20949 | -8.58310*** | 3.6923 | -6.04984*** | 2.24954 | -6.90746*** | 0.99227 | -9.10217*** |
| *Breitung* | *a)* | | 1.62416 | -0.6124 | 1.12595 | -1.86342** | 0.6693 | 0.39358 | -0.86032 | -8.14453*** | -0.95229 | -3.99652*** | -0.61824 | -6.58517*** | 2.28623 | -5.29317*** |
| *LM* | *a)* | | 0.76522 | -1.90622** | 0.19611 | -2.55200*** | 2.17257 | -1.07805 | -0.29236 | -4.97409*** | -1.54158* | -4.09298*** | 1.37024 | -2.90057*** | 0.1701 | -3.74735*** |
| | *b)* | | 1.80109 | -3.96283*** | 4.16511 | -4.53197*** | 3.46489 | -2.33992*** | 1.39743 | -6.32379*** | 2.02925 | -6.27266*** | 4.58507 | -3.95267*** | -0.71773 | -4.48750*** |
| *ADF* | *a)* | | 18.4517 | 36.4042** | 21.7339 | 40.1942** | 9.71283 | 27.6881 | 20.4927 | 63.6431*** | 30.0525 | 54.6048*** | 9.19896 | 42.3901*** | 23.9679 | 51.6200*** |
| | *b)* | | 13.4046 | 54.1681*** | 5.93257 | 59.8298*** | 7.44794 | 34.6234** | 11.9772 | 80.2162*** | 10.1375 | 79.7718*** | 1.86669 | 46.5368*** | 24.9469 | 60.4260*** |
| | *c)* | | 58.5271*** | 70.6112*** | 1.24908 | 49.0592*** | 2.30549 | 46.4908*** | 11.12 | 100.687*** | 1.68032 | 62.8654*** | 4.69254 | 64.4167*** | 9.53856 | 103.561*** |
| *PP* | *a)* | | 27.35 | 104.267*** | 21.6239 | 106.719*** | 11.1722 | 82.9711*** | 33.7661* | 163.951*** | 38.9844** | 99.5851*** | 11.4542 | 92.6378*** | 16.2102 | 63.5525*** |
| | *b)* | | 30.8088 | 107.064*** | 16.4596 | 116.837*** | 8.2691 | 75.9010*** | 22.4782 | 137.018*** | 26.4063 | 114.974*** | 1.70788 | 74.7842*** | 30.7546 | 58.4655*** |
| | *c)* | | 106.311*** | 126.222*** | 0.29777 | 86.7345*** | 1.65878 | 84.9692*** | 11.5926 | 140.565*** | 0.49954 | 94.5475*** | 4.09835 | 104.493*** | 5.86569 | 99.6253*** |
| *MW* | *b)* | *(0)* | 29.808 | 136.878*** | 16.407 | 140.279*** | 4.944 | 117.812*** | 13.421 | 146.338*** | 28.801 | 125.610*** | 1.499 | 124.895*** | 24.048 | 60.874*** |
| | | *(1)* | 13.184 | 67.545*** | 5.425 | 74.97*** | 7.096 | 46.715*** | 11.508 | 106.121*** | 9.816 | 106.321*** | 1.446 | 64.205*** | 25.39 | 77.798*** |
| | | *(2)* | 17.225 | 37.762** | 3.799 | 33.567* | 5.847 | 32.58* | 11.25 | 48.358*** | 6.423 | 61.184*** | 1.074 | 26.739 | 15.752 | 35.091** |
| | *a)* | *(0)* | 23.219 | 110.056*** | 26.397 | 115.914*** | 10.396 | 91.815*** | 22.055 | 115.736*** | 38.530** | 88.580*** | 8.113 | 94.701*** | 8.875 | 48.295*** |
| | | *(1)* | 20.967 | 44.953*** | 25.363 | 48.788*** | 9.03 | 31.348* | 21.01 | 86.504*** | 33.054* | 71.683*** | 7.665 | 51.030*** | 29.03 | 67.995*** |
| | | *(2)* | 15.002 | 29.012 | 11.398 | 22.613 | 7.589 | 27.206 | 10.784 | 32.761* | 18.913 | 51.359*** | 5.678 | 14.633 | 10.481 | 23.043 |
| *CIPS* | *b)* | *(0)* | -1.746** | -6.709*** | -2.328** | -7.097*** | 1.986 | -3.956*** | 0.947 | -4.254*** | -1.274 | -4.611*** | 3.812 | -4.278*** | 4.348 | -3.520*** |
| | | *(1)* | 1.238 | -3.284*** | 0.766 | -4.689*** | 2.861 | 1.708 | 1.848 | -2.322** | -1.183 | -1.561* | 3.451 | -2.597*** | 3.986 | -1.708** |
| | | *(2)* | 1.641 | -0.12 | 1.829 | -0.342 | 2.022 | 0.594 | 2.017 | -0.731 | -0.363 | -0.839 | 1.969 | -0.692 | 3.756 | -0.437 |
| | *a)* | *(0)* | -0.557 | -5.972*** | -1.338* | -6.454*** | 2.79 | -3.045*** | -1.236 | -3.651*** | 0.791 | -3.950*** | 0.393 | -3.690*** | 1.986 | -3.329*** |
| | | *(1)* | 2.319 | -2.381*** | 1.198 | -3.793*** | 4.51 | 2.873 | -1.006 | -0.387 | 1.386 | -0.121 | 0.125 | -2.097** | 1.021 | -1.292* |
| | | *(2)* | 2.657 | -1.097 | 3.265 | -0.262 | 2.527 | 0.991 | 2.573 | 2.057 | 2.913 | 0.1 | 1.428 | 1.451 | 0.779 | -1.202 |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively; LC indicates Levin, Lin, & Chu, (2002b) panel unit root test; Breitung indicates Breitung, (2000a) and Breitung & Das, (2005) unit root test; LM indicates Im, Pesaran, & Shin, (2003b) unit root test; ADF and PP indicates Choi, (2001b) unit root test; MW indicates Maddala & Wu, (1999b) unit root test; CPIS indicate Pesaran, (2007b) unit root test; in (.) are identified the lag order; a), b) c), indicates option with intercept and trend, only intercept and none respectively.

A.2 - Unit Roots Test (cont.)

| | | | $LI^+$ | $\Delta LI^+$ | $LI^-$ | $\Delta LI^-$ | $LIEPI$ | $\Delta LIEPI$ | $LIEPI^+$ | $\Delta LIEPI^+$ | $LIEPI^-$ | $\Delta LIEPI^-$ | $LRES$ | $\Delta LRES$ | $LEMP_R$ | $\Delta LEMP_R$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *LC* | *a)* | | -1.06563 | -4.13483*** | -0.34801 | -6.87413*** | -3.62318*** | -7.16975*** | -4.01036*** | -7.25130*** | -0.50043 | -3.57179*** | -0.58858 | -1.43124* | 0.51125 | -1.20451 |
| | *b)* | | -2.79180*** | -5.03529*** | 3.17083 | -6.14145*** | -1.81564** | -7.58853*** | -1.04518 | -7.54856*** | -0.19703 | -4.81865*** | 0.28358 | -2.19886** | 1.93199 | -3.22854*** |
| | *c)* | | 2.30101 | -6.75161*** | 3.52084 | -5.91225*** | 7.07009 | -7.19604*** | 4.48569 | -5.00258*** | 2.99756 | -7.60495*** | 3.04064 | -2.57259*** | -7.77189*** | -5.17911*** |
| *Breitung* | *a)* | | 1.20859 | -3.83083*** | 2.06561 | -4.52707*** | -3.07229*** | -2.83894*** | -2.75046*** | -2.13390** | 0.4078 | -1.33699* | -0.56138 | -0.54724 | 1.01038 | -3.45881*** |
| *LM* | *a)* | | -0.9283 | -2.78719*** | 1.6446 | -2.90509*** | -1.66936** | -4.56095*** | -1.80058** | -4.93866*** | 0.8978 | -2.59497*** | 1.36723 | -1.76703** | 0.6023 | -2.16183** |
| | *b)* | | 0.67562 | -4.44079*** | 5.35525 | -3.55389*** | 2.54512 | -6.67671*** | 3.40658 | -7.04751*** | 3.12973 | -4.22037*** | 4.61841 | -2.63106*** | 4.10943 | -3.95802*** |
| *ADF* | *a)* | | 27.5209 | 42.1148*** | 15.2127 | 42.6603*** | 31.1952* | 60.0482*** | 33.1264* | 64.5845*** | 15.7752 | 39.6332** | 15.1175 | 37.0640** | 19.6299 | 36.5284** |
| | *b)* | | 18.3081 | 59.6749*** | 3.1904 | 46.4148*** | 8.02354 | 84.5493*** | 5.70092 | 89.0499*** | 8.47817 | 56.5152*** | 8.98466 | 42.6680*** | 6.92569 | 52.9458*** |
| | *c)* | | 3.75287 | 67.8815*** | 2.852 | 57.7618*** | 0.4917 | 75.7267*** | 1.45982 | 46.4411*** | 2.49207 | 76.8749*** | 5.7577 | 32.5645* | 89.0321*** | 58.0960*** |
| *PP* | *a)* | | 31.3735* | 65.8125*** | 10.4233 | 95.6516*** | 41.3997*** | 147.284*** | 33.7407* | 133.465*** | 15.7719 | 86.2087*** | 10.3438 | 79.1592*** | 27.6107 | 114.895*** |
| | *b)* | | 54.7127*** | 89.7430*** | 1.79512 | 76.0554*** | 7.47189 | 160.115*** | 5.31158 | 151.148*** | 18.6608 | 98.8624*** | 12.5503 | 73.5320*** | 4.47832 | 122.241*** |
| | *c)* | | 1.20347 | 89.0770*** | 1.33738 | 90.7273*** | 0.26716 | 125.913*** | 0.2179 | 81.5005*** | 1.79407 | 128.085*** | 2.64084 | 61.9624*** | 129.453*** | 109.075*** |
| *MW* | *b)* | *(0)* | 91.416*** | 82.454*** | 1.748 | 95.570*** | 3.721 | 175.519*** | 2.325 | 164.594*** | 10.924 | 139.526*** | 6.043 | 96.684*** | 4.158 | 165.203*** |
| | | *(1)* | 20.503 | 75.387*** | 2.761 | 58.551*** | 7.521 | 117.467*** | 5.124 | 130.078*** | 7.967 | 67.542*** | 10.597 | 55.505*** | 6.718 | 62.138*** |
| | | *(2)* | 19.915 | 75.151*** | 3.487 | 36.179** | 7.515 | 55.860*** | 5.715 | 56.942*** | 7.984 | 39.085** | 11.531 | 18.066 | 4.918 | 50.045*** |
| | *a)* | *(0)* | 54.660*** | 57.907*** | 9.213 | 76.951*** | 41.815*** | 126.925*** | 38.895** | 116.275*** | 14.891 | 103.899*** | 10.332 | 103.443*** | 36.862** | 129.285*** |
| | | *(1)* | 30.668 | 52.425*** | 15.517 | 51.485*** | 34.432** | 83.676*** | 38.59** | 95.737*** | 15.166 | 46.05*** | 16.344 | 47.864*** | 21.385 | 42.109*** |
| | | *(2)* | 31.125* | 63.422*** | 11.417 | 26.072 | 19.43 | 35.985** | 27.486 | 35.498** | 7.858 | 46.627*** | 16.604 | 11.888 | 24.235 | 49.898*** |
| *CIPS* | *b)* | *(0)* | -1.272 | -5.178*** | 2.124 | -2.847*** | -1.390* | -5.054*** | -2.008** | -4.933*** | -1.645* | -5.829*** | 0.034 | -5.165*** | 0.131 | -7.449*** |
| | | *(1)* | -2.827*** | -2.596*** | 0.856 | 0.631 | -1.231 | -2.264** | -2.552*** | -2.539*** | 0.704 | -2.251** | -0.626 | -1.274 | 1.963 | -0.759 |
| | | *(2)* | 2.464 | -2.656*** | -1.628 | 0.359 | 1.031 | 0.159 | 1.287 | -1.161 | -0.722 | 0.089 | 0.345 | 0.17 | 2.076 | 0.282 |
| | *a)* | *(0)* | -0.255 | -4.157*** | 4.544 | -2.347*** | 0.286 | -4.744*** | -0.004 | -3.872*** | 0.168 | -5.356*** | 1.904 | -4.486*** | 1.246 | -6.481*** |
| | | *(1)* | -1.498* | -2.341** | 2.854 | 0.74 | 0.643 | -1.993** | 0.187 | -2.37*** | 2.034 | -1.522* | 1.344 | -1.752** | 3.008 | 0.397 |
| | | *(2)* | 3.099 | -4.387*** | 0.371 | -2.270** | 3.907 | 0.208 | 3.57 | -2.067** | 2.548 | -1.067 | 2.926 | 0.78 | 3.251 | 0.303 |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively; LC indicates Levin, Lin, & Chu, (2002b) panel unit root test; Breitung indicates Breitung, (2000a) and Breitung & Das, (2005) unit root test; LM indicates Im, Pesaran, & Shin, (2003b) unit root test; ADF and PP indicates Choi, (2001b) unit root test; MW indicates Maddala & Wu, (1999b) unit root test; CPIS indicate Pesaran, (2007b) unit root test; in (.) are identified the lag order; a), b) c), indicates option with intercept and trend, only intercept and none respectively.

A.2 - Unit Roots Test (cont.)

| | | | *LGHG* | *$\Delta$LGHG* | *LGHG$^{+}$* | *$\Delta$LGHG$^{+}$* | *LGHG$^{-}$* | *$\Delta$LGHG$^{-}$* | *LCOAL* | *$\Delta$LCOAL* | *LOIL* | *$\Delta$LOIL* | *LHYDRO* | *$\Delta$LHYDRO* | *LGDP$_{PC}$* | *$\Delta$LGDP$_{PC}$* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *LC* | *a)* | | -0.65151 | -4.42275*** | -0.66051 | -6.05031*** | 1.15755 | -3.33726*** | -0.45903 | -2.85289*** | 0.06027 | -5.31659*** | -2.09393** | -4.24232*** | -2.37980*** | -7.83726*** |
| | *b)* | | 3.2874 | -2.50830*** | -0.86693 | -4.90781*** | 4.88058 | -3.17466*** | -0.47901 | -4.99768*** | 0.83066 | -5.37099*** | -3.48665*** | -6.80904*** | -2.91193*** | -6.50738*** |
| | *c)* | | -5.62867*** | -8.68079*** | 3.69103 | -7.98964*** | 5.98243 | -5.42275*** | -3.20719*** | -8.75797*** | -4.59825*** | -6.82248*** | -0.23152 | -14.7028*** | 2.86334 | -6.32196*** |
| *Breitung* | *a)* | | 2.17949 | -1.80406*** | 1.55919 | -3.09974*** | 1.58602 | -0.34146 | -0.17394 | -1.96060** | 0.78498 | -4.31979*** | -1.30336* | 0.02414 | 2.43939 | -5.28867*** |
| *LM* | *a)* | | 1.70334 | -5.89734*** | 0.90189 | -5.29085*** | 2.85446 | -3.52687*** | -0.34713 | -3.61291*** | 0.32261 | -3.89665*** | -2.25182** | -5.41432*** | 1.19357 | -3.76739*** |
| | *b)* | | 3.58725 | -5.12331*** | 2.57022 | -5.02921*** | 7.2458 | -3.40588*** | 0.10308 | -5.28249*** | 2.87032 | -5.42538*** | -4.07168*** | -7.87621*** | -0.95264 | -3.61871*** |
| *ADF* | *a)* | | 14.732 | 74.5622*** | 19.364 | 68.4113*** | 7.34472 | 50.2512*** | 23.5332 | 51.3375*** | 20.2377 | 52.9889*** | 40.4036*** | 69.0011*** | 15.3312 | 51.5939*** |
| | *b)* | | 9.55831 | 68.2204*** | 18.7222 | 67.5573*** | 1.06567 | 48.7298*** | 25.5661 | 68.5516*** | 5.58822 | 70.8062*** | 55.6624*** | 96.8551*** | 25.8109 | 49.1122*** |
| | *c)* | | 56.1844*** | 97.1375*** | 2.08016 | 79.6640*** | 0.32199 | 51.0965*** | 37.6795** | 107.444*** | 49.4991*** | 75.9219*** | 13.2381 | 151.224*** | 3.30392 | 75.9298*** |
| *PP* | *a)* | | 41.7545*** | 165.087*** | 19.3640** | 154.012*** | 19.0171 | 127.322*** | 27.3429 | 131.780*** | 28.2805 | 96.4043*** | 65.3935*** | 157.615*** | 12.1141 | 91.1403*** |
| | *b)* | | 17.4862 | 153.565*** | 134.459*** | 143.299*** | 6.61141 | 115.732*** | 27.657 | 146.548*** | 4.27129 | 123.208*** | 72.6580*** | 193.939*** | 72.273*** | 60.0685*** |
| | *c)* | | 65.1521*** | 179.697*** | 1.83693 | 146.463*** | 0.19907 | 107.765*** | 47.8395*** | 169.965*** | 55.0702*** | 133.126*** | 14.5623 | 229.182*** | 1.42295 | 84.6255*** |
| *MW* | *b)* | *(0)* | 22.823 | 256.94*** | 36.759** | 199.79*** | 9.81 | 172.226*** | 30.555 | 178.509*** | 4.458 | 178.936*** | 85.366*** | 239.705*** | 54.34*** | 58.653*** |
| | | *(1)* | 9.793 | 93.846*** | 22.652 | 92.984*** | 0.869 | 60.767*** | 28.893 | 94.866*** | 4.913 | 103.198*** | 72.623*** | 173.213*** | 30.07 | 52.962*** |
| | | *(2)* | 7.617 | 23.115 | 111.738*** | 53.81*** | 0.416 | 15.756 | 20.257 | 43.565*** | 8.159 | 43.143*** | 35.256** | 73.113*** | 27.621 | 38.843** |
| | *a)* | *(0)* | 34.279** | 244.861*** | 52.1*** | 173.743*** | 23.017 | 161.951*** | 31.901* | 137.15*** | 34.466** | 130.335*** | 60.426*** | 181.143*** | 8.193 | 60.277*** |
| | | *(1)* | 16.02 | 132.643*** | 21.225 | 128.936*** | 6.313 | 69.222*** | 25.876 | 73.307*** | 21.363 | 89.007*** | 57.296*** | 129.893*** | 17.799 | 65.501*** |
| | | *(2)* | 8.498 | 22.273 | 58.723*** | 38.079** | 6.253 | 12.258 | 27.21 | 24.492 | 26.087 | 28.069 | 34.861** | 48.122*** | 13.245 | 31.97* |
| *CIPS* | *b)* | *(0)* | -2.219** | -7.214*** | 0.242 | -5.372*** | -1.621* | -7.198*** | -1.047 | -8.812*** | -1.212 | -7.307*** | -4.681*** | -9.863*** | 1.344 | -1.978** |
| | | *(1)* | -0.451 | -4.671*** | 0.709 | -1.471* | -0.579 | -4.92*** | 0.02 | -3.831*** | -0.381 | -4.558*** | -2.366*** | -5.104*** | 2.178 | -0.651 |
| | | *(2)* | 1.018 | -0.935 | 0.16 | 0.006 | 1.072 | -0.116 | -0.018 | -2.626*** | 0.069 | -0.966 | -0.785 | -1.294* | 1.434 | 0.416 |
| | *a)* | *(0)* | -2.207** | -5.647*** | 1.916 | -5.212*** | -1.263 | -5.452*** | -1.426* | -8.159*** | -1.122 | -5.642*** | -3.888*** | -8.146*** | 3.346 | -1.059 |
| | | *(1)* | -1.943** | -2.369*** | 2.514 | -2.424*** | -2.15** | -1.964** | -0.095 | -3.265*** | -1.977** | -3.986*** | -1.475* | -3.22*** | 1.384 | -0.245 |
| | | *(2)* | 1.496 | 2.079 | 3.708 | 0.144 | 0.087 | 2.42 | -0.318 | -1.106 | 1.22 | -1.005 | 0.091 | 1.156 | 1.721 | 1.992 |

Notes: ***, **, * denotes 1%, 5% and 10% of significance respectively; LC indicates Levin, Lin, & Chu, (2002b) panel unit root test; Breitung indicates Breitung, (2000a) and Breitung & Das, (2005) unit root test; LM indicates Im, Pesaran, & Shin, (2003b) unit root test; ADF and PP indicates Choi, (2001b) unit root test; MW indicates Maddala & Wu, (1999b) unit root test; CPIS indicate Pesaran, (2007b) unit root test; in (.) are identified the lag order; a), b) c), indicates option with intercept and trend, only intercept and none respectively.